FUNDAMENTAL DESICCANTS

MARK E. KREBS

Gas Utilization Engineer

Southern Union Gas Company

Austin, Texas

ABSTRACT

The purpose of this paper is to familiarize the mainstream HVAC and facility management community with the technical concepts and emerging role of desiccant dehumidification alternatives and various hybrids thereof. The methodology employed to present this information begins with a discussion of basic physical properties. This is followed by a discussion of typical applications where desiccant dehumidification technologies can be effectively utilized. The paper continues with a discussion of why desiccants aren't used more often and what can be done to increase the mainstream awareness of these technologies. Then, the paper concludes with a discussion of how desiccant dehumidification potential is physically determined.

WHAT IS AIR?

Air is a homogenous mixture of gases; approximately consisting of 77 percent Nitrogen, 22 percent Oxygen and 1 percent miscellaneous by weight.

Among the 1 percent of "miscellaneous" gases found in air is water vapor. The minor presence of water vapor in air is a major concern in commercial air conditioning. Also, this 1 percent contains a growing amount of other gases, such as carbon-dioxide, and impurities, such as dust, pollen, viruses, hydrocarbon emissions and other "rare" gases, such as radon. These impurities can and do become major health risks when they exceed quantified limits.

WHAT SHOULD AIR CONDITIONING ACCOMPLISH?

Provide adequate oxygen (O_2) supply and removal of carbon-dioxide (CO_2) to maintain occupant health.

Human respiration removes O_2 and adds CO_2 to the air through the lungs. Without a minimum amount of "make-up" air, brought in from outdoors, respiration is adversely affected. Minimum outside air requirement standards are determined by local agencies with considerations made for the type of activity the facility is designed for.

Typically, present office building codes & standards call for 5 cubic feet per minute (CFM) of outside air per person. However, new standards have been proposed to increase outside air requirements to a minimum of 15 CFM per person. Other potential impurity issues aside, the general purpose of outside air is to reduce CO_2 levels

Add or remove heat and humidity necessary for comfort and/or manufacturing process requirements.

Building exteriors transfer heat. Insulation is used to slow down the rate of heat transfer. In the summer, heat is mainly transferred to the interior. In the winter, the opposite occurs. However, winter heat loss is significantly offset by internal heat gain caused by people and/or equipment; to the extent that the amount of energy used to keep modern air conditioned buildings cool is almost always more than the amount of energy used to keep a building warm; even in the Northern climates. In most situations and/or seasons, temperature reduction is where most air conditioning energy is consumed. Sometimes however, humidity reduction is the dominate air conditioning load, especially when there is a large make-up air requirement or when variable air volume (VAV) systems operate at part load. Temperature reduction is much easier to accomplish in comparison to humidity reduction for traditional HVAC (heating, ventilation and air conditioning) systems.

Control air impurity level required for health and/or process requirements

Dust, pollen, bacteria, viruses and radon gas are naturally occurring impurities in the air we breath. Air may also contain many pollutants common to industrialized society such as hydrocarbon emissions. Also, many of the materials used in construction and furniture produce noxious fumes through "out-gassing". Make-up air requirements are intended to dilute these impurities to acceptable level and is used in conjunction with air filtration systems..

HOW ARE TEMPERATURE AND HUMIDITY LINKED?

Proceedings of the Seventh Symposium on Improving Building Systems in Hot and Humid Climates, Fort Worth, TX, October 9-10, 1990

With any gas, or mixtures of gases such as air, factors of temperature, pressure and volume are intimately linked. A change in one of these factors must be balanced by a change in any of the other two factors. Consider the physics of an inner-tube. Adding air both inflates the inner-tube and increases its pressure. If a semi-inflated inner-tube was gently heated and there were no leaks, it would inflate and/or gain pressure without adding air; only the volume the air occupies and/or the pressure it exerts against the interior tube wall is changed. Since there is a fixed amount of air (by weight), there is a fixed amount of associated water vapor in the air. However, the <u>relative</u> amount of water vapor, in relation to the <u>volume</u> of air it is mixed in, becomes less as the volume increases due to temperature based expansion. The <u>specific humidity</u> within the inner-tube remains unchanged (in relationship to the weight of air) unless more water vapor is physically injected. Therefore, <u>relative humidity</u> within the inner-tube decreases with an increase in temperature/volume and increases with a decrease in temperature/volume; but <u>specific humidity</u> is constant.

HOW DO DESICCANTS OPERATE WITH AIR CONDITIONING?

Minor changes in humidity can cause major changes in comfort levels and/or manufacturing process quality control requirements. Inevitably, the more water vapor to be removed from the air stream to be conditioned, the harder the refrigerant compressor has to work to achieve low enough cooling coil temperatures to cause this water vapor to condense. In traditional commercial air conditioning, dehumidification is accomplished on the cooling coil by the same method that moisture condenses on the outside of a cold drink. To do this, a cooling coil has to be much colder than needed to simply lower the (sensible) temperature of the air to the desired level. As a result, a refrigerant compressor has to operate at a much higher compression ratio. This takes more energy in the form of shaft horsepower and more elaborate/expensive cooling coils. If cooling coils didn't have to dehumidify as well, the system could operate at greatly reduced ratios of horsepower per ton (hence higher COP's). Desiccants can free the compressor to do only cooling. Relatively moderate temperature heat (i.e., 150 F to 200 F) can be used to regenerate these desiccants. Because of these relationships, using engine driven refrigerant compressors for space cooling in conjunction with engine and compressor heat recovery for desiccant based space dehumidification can be very energy efficient and is being evaluated for possible commercial development.

Desiccants are materials that "hold" a large capacity of moisture relative to their volume and weight. The term for used for holding this moisture is sorption. The term sorption is divided into two major categories:

<u>Adsorption</u>

Contrary to popular belief, paper towels and sponges do not absorb spills; they adsorb spills. In adsorption, the material used as a desiccant does not change physically or chemically as moisture is added or removed. Adsorption takes place on the surface of the material. Moisture is retained within these materials by a combination of molecular forces. Typical commercial adsorbents are extremely porous when viewed under a microscope. In fact, some adsorbents possess as much as 115 acres of surface area per pound of dry material. Silica gel is a familiar example of an adsorbent.

<u>Absorption</u>

These materials are chemically and/or physically altered by the addition or removal of moisture. As moisture enters an absorbent, the material becomes more and more hydrated. Eventually, absorbents reach a saturation point; after which, the material becomes a liquid solution with moisture it contains. Salts and alcohol are familiar examples of absorbents.

By strict definition, only solid adsorbents are referred to as desiccants. For the purposes of this paper however, desiccants can be either solid or liquid, adsorbent or absorbent. In reality, some materials such as salts can be either, depending upon their moisture content. In either case, moisture is removed from these materials by heat. The term used to remove moisture from desiccants is "regeneration".

In order for water vapor to liquefy, 970 BTU's are released for every pound of water condensed. Conversely, a pound of water must absorb 970 BTU's to change from liquid to vapor (i.e., evaporate). This value of 970 BTU's per pound is a theoretical minimum that only pertains to the transformation of water into steam and visa versa. In practice, it takes more than 970 BTU's because the processes of heat transfer and/or combustion are never 100% efficient. However, most desiccant dehumidification systems are "open cycles" (versus "closed cycles" typified by vapor compression refrigeration). With "open cycles" the ambient environment can supply some of the energy for changing the phase of water liquid to water vapor. Therefore, the efficiency of desiccant dehumidification systems is largely determined by ambient humidity levels; as is the case with cooling towers and "swamp coolers". The lower the ambient humidity, the easier it is to evaporate moisture. Consider two equally filled bowls of water; one in a 100 degree F desert and the other in a 100 degree F rain forest. Which one would evaporate first? Common sense tells us that the one in the desert would evaporate first. The reason for this is the difference in "vapor pressure" that the water in the bowls have to overcome in order to evaporate. The vapor pressure in a dry desert environment is less than the vapor pressure in a humid rain forest environment.

The term used in refrigeration for efficiency is "Coefficient of Performance" (C.O.P.). The COP is simply a ratio of energy output (in terms of cooling, heating or dehumidification) divided by energy input where the units of each term is the same. Energy inputs for COP calculations should include "parasitic" loads associated with miscellaneous fans, pumps, etc., necessary for the system to operate. Present technology desiccant dehumidification systems exhibit thermal COP's between 0.4 and 1 in the field. Advanced technologies have exhibited COP's as high as 1.4 in laboratory environments. Some desiccant dehumidification system manufacturers refer to efficiency in terms of "thermal C.O.P's" and "parasitic EER's"; where thermal C.O.P refers to the dehumidification effect divided by the regeneration energy, and EER refers to the dehumidification effect (in terms of BTU's per hour) divided by the parasitic electric requirements (in terms of Watts).

For commercial use, an optimum desiccant material must:

* Be able to indefinitely withstand cycling between moisture adsorbing/absorbing and moisture releasing
* Be relatively noncorrosive, odorless, nontoxic and nonflammable.
* Readily accept and reject moisture (i.e., be energy efficient)
* Withstand contamination and/or be easily cleanable.
* Be inexpensive

There are presently two predominant types of desiccant dehumidification systems that dominate the U.S. market. One of these systems uses dry desiccant impregnated "honeycomb" wheels that slowly turn within an air duct. The other uses a desiccant based liquid solution that is sprayed in a fine mist within an air duct. Both of these systems use Lithium Chloride (a type of salt) as the desiccant. Either system has positive and negative attributes as compared with the other. Liquid desiccant draw-backs include weight (due to the volume of liquid), pump energy and increased fan energy (due to the addition of mist eliminators in the duct-work to eliminate carry-over). Dry desiccant wheel systems are relatively lightweight and can usually be placed on the roof with little difficulty. If these wheels utilize hydratable salts, such as lithium chloride, that are left idle and allowed to encounter humid environments, the desiccant impregnated within the fibers of the wheel can become saturated and actually drip off (liquesce). Then, when the air flow returns, this salt solution can be carried into the duct work where quick and serious corrosion can occur. Silica Gel is emerging as an alternative to lithium chloride for desiccant wheels; primarily because silica does not liquesce. Various glycols are used as alternatives in liquid systems as well. Other desiccant contenders, primarily under development, include aluminas, zeolites, clays and certain types of polymer beads. Some polymers can hold up to 10,000 times their dry weight in water.

In addition to the primary use of desiccants for humidity removal, some desiccants remove unwanted gases and other impurities as well. Liquid desiccants can control many types of bacteria and viruses and help filter air through an "air-washing" effect. With the growing concern for indoor air quality (IAQ) and the "sick building syndrome", air purification side benefits of desiccants can provide important incentives in addition to those of reduced air conditioning system operating costs.

Desiccants have been used in conjunction with air conditioning and refrigeration systems since the early 30's. However, most of these uses (up to this point) have been for specialty applications requiring very strict and/or low humidity levels.

WHAT APPLICATIONS CAN BEST UTILIZE DESICCANTS?

To Increase Cooling Capacity in Existing Buildings

With the advent of personal computers and modular work spaces (better use of floor space, hence less square footage per occupant), air conditioning loads have increased significantly due to internal heat gain from these sources in most office environments. Frequently, comfort levels suffer and/or fresh air requirements are reduced in an effort to cope with these increased loads imposed by changing office use patterns unless the system was considerably over-sized to begin with. Additionally, cooling system machinery and component performance tends to degrade in time due to heat exchanger fouling and corrosion, compressor wear, etc. As explained previously, removing humidity (via desiccants) upstream of cooling coils, allows these coils to deliver more capacity due to lower compression ratios. Therefore, less horsepower is required by the compressor per ton of delivered capacity and efficiency (in terms of C.O.P.) is increased. Graphs 1 to 5, in the appendix, illustrate these effects for the combination of a Carrier 5H120 reciprocating compressor operating with R-22 and powered by a Caterpillar 3306NA high compression ratio natural gas engine.

Environmental concerns over potential upper atmosphere ozone depletion have been increasing. This problem has been linked to the use of specific types of man-made chemical compounds commonly used as refrigerants (among other uses). These compounds are commonly referred to as CFC's (standing for chlorofluorocarbons) and are formulated by substituting chlorine, fluorine and bromine for hydrogen atoms in hydrocarbons. These hydrogen substitutes react with ozone in the upper atmosphere causing the ozone to break down. Unfortunately, the ozone is what shields us from ultra-violet radiation, the major cause of skin cancer. Also, increased ultra-violet radiation turns into heat once it reaches the planet surface, contributing to global warming. The major manufacturers of CFC's are rapidly phasing out production and substituting them with HCFC's. HCFC's are a more environmentally benign variety of CFC due to less substitution of hydrogen molecules in these compounds.

Centrifugal chillers dominate the market for central plant comfort cooling systems at present. Almost all centrifugal chillers use R-11 or R-12 CFC's as refrigerants. The new HCFC refrigerants, slotted for replacement of R-11 and R-12, have serious drawbacks and/or may not be compatible for existing chiller motor windings, lubricating oils, etc. At the least, a 15 to 30 percent reduction in refrigeration capacity should be expected. By divorcing sensible temperature reduction from humidity reduction via desiccant dehumidification upstream of cooling coils, evaporator temperatures (hence pressures) can be increased. In turn, elevated evaporator temperatures/pressures lowers the compression ratio. The effect of reducing compression ratios allows for increased chiller capacity and COP. Capacity shortfalls induced from environmentally acceptable refrigerant change-outs may be offset through the use of desiccant dehumidification systems in this manner. In certain situations, engines can be retrofit to centrifugal chillers at the same time as a "demand side management" strategy and as a free source of desiccant regeneration thermal energy.

To Reduce The "Sick Building Syndrome"

Indoor air quality (IAQ) is becoming a major health concern due to rising occurrences of "Sick Building Syndromes" and "Building Related Illnesses"; the latter being much more serious in terms of potential adverse and long term health consequences. People can become "sensitized" to indoor emissions to the point that medical intervention is necessary. Unfortunately, this usually leads to legal intervention and multi-million dollar settlements have been awarded due to IAQ lawsuits.

The primary means of correcting IAQ problems is to increase fresh air flow and/or decrease humidity in conjunction with correcting and insuring adequate filtration and maintenance of air handling systems. Typically, present codes require a minimum of 5 CFM of outside air per person to maintain an adequate oxygen supply and CO2 removal rate. Proposed ASHRAE Standard 62-1989 (entitled Ventilation for Acceptable Indoor Air Quality) recommends outside air ranges from to a minimum of 15 CFM per person in office corridors to a maximum of 60 CFM per person in smoking lounges. Simultaneously, this standard also recommends maximum duct relative humidity levels of 70 percent. Since air moving past cooling coils is typically at or near 100 percent relative humidity, (due to the fact that traditional humidity reduction occurs as a result of humidity condensation upon these coils) energy inefficient reheat of this air, in conjunction with further decreasing coil temperatures, may be necessary to insure that maximum duct humidity is maintained while still meeting the comfort conditions design setpoints of the space.

In many buildings, existing chiller capacities are already inadequate due to greater interior concentrations of people and equipment. The issues of whether or not "grandfather clauses" are allowed for existing "sick buildings" has not been addressed by ASHRAE. Federal, regional, state and local code authorities will be faced with how and when these standards are interpreted and implemented. Undoubtedly, the emerging trend of increasing amounts of IAQ lawsuits will come to bear upon this situation.

Potentially, supplemental cooling retrofits may become widespread in order to meet IAQ requirements. However, the associated costs and temporary disruption in the workplace may be more than compensated by increased worker productivity brought about by a healthier environment. ACVA Atlantic, Inc., a Fairfax, VA, consulting firm, has estimated an $18,500 additional yearly operating cost to meet these new requirements in a "typical" Washington D.C. 100,000 sq. ft. office building. Assuming 150 sq. ft. per person, this equates to 667 people. Further assuming an average yearly salary of $20,000 per person, this equates an annual payroll of $13.34 million. However, if absenteeism declines by only 1%, this expense would be offset by a $133,400 yearly increase in worker productivity.

To Control Hi-Tech Manufacturing Process Environments

Many manufacturing processes, such as micro-electronics and pharmaceuticals production, require stringent humidity control of the production environment. The process, and raw material, of plastic injection molding is also very susceptible to humidity. In the manufacturing arena, new technologies are much more accepted than in the commercial HVAC market. Also, industrial grade air conditioning equipment is significantly more expensive than commercial grades; therefore the incremental costs for gas alternatives are less. Simultaneously, industrial air conditioning decision makers are willing to make major equipment investments; if productivity can be improved. However, their decisions are usually based upon thorough economic analysis of the options versus most commercial building equipment decisions that tend to be based on tradition and perceptions. This market seems to be equally shared by Cargocaire and Kathabar.

To Reduce Frozen Food Defrosting in Super Markets

The corporate engineering staffs of large super-market chains, such as H.E. Butts, are becoming aware of the effects that internal humidity has on frozen food merchandising. When humidity freezes on frozen food packaging in sufficient quantities, it obscures visual aesthetics, and must be defrosted. Defrosting reduces shelf life and frost reduces the marketability of frozen food products. Desiccant dehumidification is becoming an accepted technology to reduce frost build-up and subsequent defrosting. Shopper comfort may also be increased due to less cold air spillage into the frozen food aisles; supposedly increasing frozen food purchases. Cargocaire developed a system specifically for this market and has sold over 130 systems to date.

To Prevent Mildew and Mold

Mildew and mold are fungus growths that occur in environments subject to prolonged and elevated humidity levels. Many people are allergic to mildew and molds. Mildew and molds are also a major concern to certain industries such as food processing and chemical manufacturing. Additionally, the American Hotel and Motel Association (AHMA) is concerned with damage to interiors and furnishings caused by mildew and mold. This association has recently formed a special committee for mildew control. One member of this committee estimated yearly mildew damage expenses in the Gulf Coast regions between $1,000 and $5,000 per room. In comparison with reduceing mildew damage, potential energy savings take a distant second place in the overall economic benefits. A similar situation may exist in these regions for dormitories, nursing homes, etc. Cargocaire is developing a system specifically for this market.

To Prevent Corrosion

Rusting of ferrous metal parts and machinery within warehouses can be significantly reduced through desiccant dehumidification. Cargocaire has targeted this market.

To Reduce Humidity Damage Within Indoor Pool Environments

Many health clubs and hotels have inside pools and/or Jacuzzi's. The combination of warmth, humidity and chlorine can quickly damage the structural integrity of these buildings. Desiccant dehumidification systems can be very cost effective in these environments. Kathabar has targeted this market.

WHY AREN'T DESICCANTS USED MORE COMMONLY?

Need to Educate HVAC Industry

The mainstream HVAC industry is virtually unaware of desiccant system benefits. This is probably because many of the potential benefits of desiccants, such as reduced worker absenteeism, have not been thoroughly subjected to the rigors of extensive case history developments, technical journal publications and seminar presentations that is necessary to bring about change in an infrastructure as tradition-oriented as the HVAC industry. Also, the major manufacturers of traditional refrigeration equipment have an extremely vested interest in maintaining and promoting existing product lines. Desiccant dehumidification competes with traditional technology manufacturers.

Need to Develop Analysis Tools

Quantifying desiccant economics for commercial applications is presently difficult due to a lack of accepted design analysis methodologies incorporated into any popular building energy analysis software.

Need to Decrease First Cost Premiums

Desiccant based dehumidification systems are not mass produced at present, and their use is primarily limited to industrial manufacturing process environments. Thus, their first cost is significantly higher per ton than comparable size ranges of traditional mechanical vapor compression systems of commercial grades. However, desiccant based dehumidification technologies are rapidly advancing and commercial grade systems are being developed. Therefore, the costs for desiccant dehumidification equipment should decline significantly as the market develops.

WHAT IS REQUIRED TO EFFECTIVELY EMPLOY DESICCANT ALTERNATIVES?

Diagnose the Problem(s) Before Prescribing a Remedy

A thorough quantification of desiccant alternatives and economics frequently involve several technical disciplines in order to fully address the multi-dimensional nature, extent and ramification of the problem(s) and potential alternatives. Desiccants are not a panacea or a substitute for good maintenance, filtration, etc. Desiccants should be another potential tool in the kit of HVAC design service and consulting professionals. There is a considerable "learning curve" associated with understanding desiccant alternatives. Also, care must be taken to avoid "concept shock" during this learning curve.

Understand the Trade Disciplines

The effects of humidity in air conditioning are readily quantified via the psychometric chart and a sling psychometer. The "psych chart" is a graphical representation of mathematical formulas developed by one of the pioneers of commercial air-conditioning, Dr. Willis Carrier, in 1911 and is the basis for many types of HVAC application engineering such as coil selection, cooling tower performance, etc. The basics of psychometric charts are reviewed in the appendix. A sling psychrometer is simply a thermometer with a wetted "sock" on the bulb. By attaching a string to the other end of the thermometer and "slinging" it around, the water evaporates and cools the thermometer. Then, the temperature is read. This reading is called the "wet bulb temperature" and indicates the "degree" of moisture present in the air being sampled. The more moisture in the air, the higher the wet bulb reading will be due to the reduced ability of the wet sock to evaporative cool the thermometer. Wet bulb temperature readings, in conjunction with dry bulb temperature readings (the temperature indicated by normal thermometers) establish the parameters necessary for a psychrometric analysis. Usually, these thermometers are mounted on a common base with a swivel and handle for slinging so that wet bulb and dry bulb readings can be taken simultaneously for convenience and greater accuracy.

In many cases, especially for IAQ concerns, air sampling techniques, procedures equipment and testing are usually required. This is the speciality of environmental toxicologists who further specialize in IAQ. These abilities are rarely present at the level of HVAC service organizations or engineering consultants who specialize in HVAC applications.

Understand Systems Alternatives and Costs

There are many viable alternatives to consider for refrigerating, dehumidifying and purifying air. Filtration methods, such as electrostatic precipitators, compete with hospital grade air filters and activated carbon. Duct humidity can be decreased by terminal reheat, supply to exhaust air-to-air heat exchangers or increasing the percentage of return air relative to supply air. Dehumidification alternatives, if considered competes with electric vapor compression alternatives to thermal regenerated desiccants. Energy alternatives for thermal regeneration also exist. Cogeneration or engine driven chillers can provide regeneration energy and desiccants may then stored in a manner similar to off-peak ice storage. The economic viability of desiccant alternatives depends upon the extent that equipment can be integrated into systems that maintain temperature, humidity and purity with a minumum of complexity, first cost and operating costs as compared to the many alternatives that exist. The ability to determine such alternatives is not widespread.

The following factors provide the basis of analyzing these alternatives:

* Evaluate Seasonal Effects

  HVAC equipment selection is traditionally based on worst-case scenarios (i.e., to meet comfort or performance specifications during near extreme weather situations). The vast majority of the time, equipment is loafing (to varying extents) if it is running at all. The further away a specific application is from the tropics, the more this tendency is pronounced.

* Evaluate Utility Rate Effects

  The energy requirements of a particular piece of equipment need to be addressed in conjunction with locally prevailing utility rates and applications in order to determine associated operating costs. The economic sensitivities of declining block rates, demand ratchets and take-or-pay clauses, among other possible scenarios, also need to be examined.

* Determine System Performance

  All of the above listed criteria are dynamically inter-related. The relationships and magnitudes of air dehumidification and temperature adjustments, as well as utility charges, do not occur at a fixed rate throughout the year. For these reasons, building HVAC design and economic analysis on an hour-by-hour simulation via personal computers can assist engineers to better evaluate and compare alternative HVAC system performance. Several of these programs are being used by increasing numbers of HVAC designers and consultants to quantify the economics of alternative HVAC strategies. Unfortunately, the emerging role and modeling ability of desiccant dehumidification and/or air purification is not sufficiently recognized and/or too recently developed to be incorporated into these programs. As computerized hour-by-hour building energy simulation programs evolve to address the dynamics humidity mass flow, quantification of desiccant dehumidification systems will become much more accurate. As this occurs, it is expected that the use of desiccants, in conjunction withmainstream HVAC systems, should increase.

SUMMARY OF DESICCANT MARKETING STRATEGIES.

Increased air conditioning loads are resulting from new mandates to increase outside air requirements. Also, the types of refrigerants used extensively for traditional centrifugal chillers that dominate the large tonnage market are being phased out due to environmental concerns with upper atmosphere ozone depletion. Desiccant dehumidification technologies represent unique opportunities and strategies to help address these problems. However, the present use of desiccant alternatives is limited due to:

* A relatively widespread lack of knowledge concerning these technologies and system integration strategies such as engine driven chillers.
* The immature but rapidly evolving science and mass production technologies.
* An entrenched, institutionalized HVAC equipment industry that does not benefit from potential desiccant technology market penetrations.

At present, niche markets exist for these technologies. These niche markets can be used to "trickle-down" desiccant knowledge into the mainstream HVAC marketplace. As technology first-cost premiums are reduced, efficiencies improve and HVAC benefits are demonstrated in the commercial sector, mass-markets may develop. With time, and effort, commercial desiccant dehumidification systems may emerge as a mainstream HVAC technology, especially where humidity reduction is a large percentage of overall air conditioning requirements.